



(Mark-up)

RADIOWAVE MONITORING METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to a radiowave monitoring method and apparatus which can identify a location of a radiowave emitting source, such as an illegal radio station or the like usage, in a prescribed area and monitor radiowave ~~using~~ environments.

Conventionally, in identifying a location of a radiowave emitting source, such as an illegal radio station in a prescribed area, monitor stations are disposed at a plurality of positions, and the respective radiowave monitor stations observe arrival bearings of the radiowaves from the radiowave emitting source by means of Yagi-Uda array antennas, goniometers or others. The respective monitor stations plot the arrival bearings on a map to thereby estimate the location of the radiowave emitting source, based on an intersection of the respective bearings.

The above-described conventional method is based on the presumption that radiowaves from a radiowave emitting source being monitored propagate rectilinearly along a single path to a monitor station. Actually,

however, radiowaves from a radiowave emitting source ~~propagate~~ propagated to a monitor station, in some cases ~~being~~ are diffracted by or reflected on topographies, and ground objects, such as buildings, etc. Radiowaves from a radiowave emitting source ~~propagate~~ propagated to a monitor station, in other cases, are separated in multi-paths under the influence of topographies and ground objects. The estimation of a location of a radiowave emitting source ~~being monitored~~ by the conventional method noted above has a problem that radiowaves ~~propagate, being~~ are diffracted or reflected or ~~in~~ divided into multi-paths, which lowers accuracy of estimating the location of the radiowave emitting source.

The inventors of the present application already proposed a wide-area radiowave monitoring method and apparatus which can solve the above-described problem (refer to, e.g., Japanese Patent Application Laid-Open Publication No. Hei 11-326482 (1999)).

In the wide-area radiowave monitoring method described in Japanese Patent Application Laid-Open Publication No. Hei 11-326482 (1999), ~~in~~ through a computer simulation, one or more monitor stations are disposed in a certain area, radiowave emitting sources are assumed to be present at a plurality of locations in the area, and arrival bearings of radiowaves from the

radiowave emitting sources, ~~which include~~ that propagate to the monitor stations are computed for the respective radiowave emitting sources, ~~using~~ incorporating the topographical information of the area, while the monitor stations observe, for respective divided propagation paths, radiowaves from a radiowave emitting source. The arrival bearings observed by the monitor stations, and the results of the computer simulation are compared with each other to ~~probe~~ detect the computer simulation results for arrival bearings of the results, which are most similar to the observed arrival bearings of the radiowaves, and a corresponding location is judged to be ~~an alleged~~ a potential location of the radiowave emitting source. Further, on the presumption that the radiowave emitting source is present near the ~~alleged~~ potential location, the computer simulation is executed, while adjusting a location of the radiowave emitting source, to thereby determine ~~a~~ the final location of the radiowave emitting source.

The above-described method can accurately determine a location of a radiowave emitting source even in a case that radiowaves are diffracted or reflected.

However, in the wide-area radiowave monitoring method and apparatus described in the specification of Japanese Patent Application Laid-Open Publication No.

326482/1999 Hei 11-326482 (1999), arrival bearings of radiowaves incoming to the monitor stations from radiowave emitting sources at a plurality of locations in an area are computed by the computer simulation for the respective locations, which requires a plurality of sets of a data base provided by the computer simulation of the radiowave propagation to be prepared for unidentified radiowave emitting sources. Furthermore, it takes much time to prepare the data base.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a radiowave monitoring method and apparatus which can shorten the time for preparing a data base for the radiowave propagation simulation to make the radiowave monitor more efficient.

The above-described object is achieved by a radiowave monitoring method ~~comprising: the step of~~ comprising the steps of: comparing an observation result of an arrival direction and a pattern of intensities observed pattern of intensities versus arrival directions of a radiowave, which is emitted from a radiowave emitting source, observed at one position in an observation area with ~~simulation results of arrival directions and patterns of intensities of radiowaves~~

simulated patterns of intensities at other plural positions in the observation area versus emitting directions of a simulated radiowave emitted from said the one position, which are to be observed at other plural positions in the observation area the simulated patterns being obtained while changing the emitting direction of the simulated radiowave; and

identifying a position out of the plural positions whose simulated pattern shows the best correlation with the observed pattern at the one position as a location of the radiowave emitting source.

~~In the above-described radiowave monitoring method, it is possible that of said plural positions whose simulation result shows the arrival direction and the pattern of intensities of the radiowave most correlated with the observation result at said one position is identified as a location of a radiowave emitting source.~~

In the above-described radiowave monitoring method, it is possible that in ~~simulating the arrival directions and the patterns of intensities of radiowaves~~ creating the simulated patterns of the intensities versus the emitting directions of the simulated radiowave emitted from ~~said the~~ the one position, the observation area is two-dimensionally divided into a plurality of regions, and electric field intensities to be observed in the

respective regions are computed.

In the above-described radiowave monitoring method, it is possible that in ~~simulating the arrival directions and the patterns of intensities of radiowaves~~ creating the simulated patterns of the intensities versus the emitting directions of the simulated radiowave emitted from ~~said~~ the one position, the observation area is three-dimensionally divided into a plurality of spaces, and electric field intensities to be observed in the respective spaces are computed.

In the above-described radiowave monitoring method, it is possible that ~~simulating the arrival directions and the patterns of intensities of radiowaves~~ in creating the simulated patterns of the intensities versus the emitting directions of the simulated radiowave emitted from ~~said~~ the one position, while changing the ~~emission~~ emitting direction of ~~radiowaves~~ the simulated radiowave emitted from ~~said~~ the one position, the electric field intensities to be observed in the respective regions or the respective spaces are computed to give electric field intensity distributions for the respective ~~emission~~ emitting directions.

In the above-described radiowave monitoring method, it is possible that ~~simulating the arrival directions and the patterns of intensities of radiowaves~~ in creating the

simulated patterns of the intensities versus the emitting directions of the simulated radiowave emitted from ~~said~~ the one position, geography and ground objects in the observation area are taken into consideration.

In the above-described radiowave monitoring method, it is possible that based on the location of the identified radiowave emitting source and the simulation result, propagation path of the ~~radiowaves~~ radiowave from ~~said one position to~~ the radiowave emitting source to the one position is traced.

In the above-described radiowave monitoring method, it is possible that based on a result of tracing the propagation path, antenna directivity of the radiowave emitting source is estimated.

In the above-described radiowave monitoring method, it is possible that based on the estimated antenna directivity of the radiowave emitting source, an electric field intensity distribution of the ~~radiowaves~~ radiowave emitted from the radiowave emitting source is computed.

The above-described object is also achieved by a radiowave monitoring apparatus comprising: a radiowave observing means disposed at one position in an observation area, for observing a pattern of intensities versus arrival directions ~~and patterns of intensities of radiowaves~~ of a radiowave emitted from a radiowave

emitting source; a storing means for storing ~~simulation~~
~~results of arrival directions and patterns of intensities~~
~~of radiowaves~~ simulated patterns of intensities at other
plural positions in the observation area versus emitting
directions of a simulated radiowave emitted from said one
position, ~~which are to be observed at other plural~~
~~positions in the observation area~~ the simulated patterns
being obtained while changing the emitting direction of
the simulated radiowave; and a radiowave emitting source
identifying means for comparing ~~an observation result~~
~~given~~ the pattern observed by the radiowave observing
means with the ~~simulation results~~ simulated patterns
stored in the storing means to identify ~~that~~ a position
out of said the plural positions whose simulation result
~~shows the arrival direction and the pattern of~~
~~intensities of the radiowave most correlated~~ simulated
pattern shows the best correlation with the ~~observation~~
~~result~~ pattern observed by the radiowave observing means
at ~~said the~~ one position as a the location of a radiowave
emitting source.

In the above-described radiowave monitoring
apparatus, it is possible that the storing means
two-dimensionally divides the observation area into a
plurality of regions, and computes electric field
intensities of ~~radiowaves~~ the simulated radiowave emitted

from ~~said~~ the one position, which are to be observed in the respective regions.

In the above-described radiowave monitoring apparatus, it is possible that the storing means three-dimensionally divides the observation area into a plurality of spaces and computes electric field intensities of ~~radiowaves~~ the simulated radiowave emitted from ~~said~~ the one position, which are to be observed in the respective spaces.

In the above-described radiowave monitoring apparatus, it is possible that the storing means stores electric field intensities of ~~radiowaves~~ the simulated radiowave emitted from ~~said~~ the one position in different directions, which are to be observed in the respective regions or the respective spaces, for the respective directions.

In the above-described radiowave monitoring apparatus, it is possible that the apparatus further comprises a propagation path tracing means for tracing a propagation path of ~~radiowaves from said one position to~~ the radiowave from the radiowave emitting source to the one position, based on the location of the radiowave emitting source identified by the radiowave emitting source identifying means and the simulation result.

In the above-described radiowave monitoring

apparatus, it is possible that the apparatus further comprises an antenna directivity estimating means for estimating antenna directivity of the radiowave emitting source, based on a result of tracing the propagation path given by the propagation path tracing means.

In the above-described radiowave monitoring apparatus, it is possible that the apparatus further comprises an electric field intensity computing means for computing an electric field intensity distribution of ~~radiowaves~~ the radiowave emitted from the radiowave emitting source, based on the antenna directivity of the radiowave emitting source estimated by the antenna directivity estimating means.

As described above, according to the present invention, an ~~observation result~~ observed pattern at one position is compared with ~~simulation results of arrival~~ simulated patterns of emitting directions and patterns of intensities of radiowaves of a simulated radiowave emitted from ~~said~~ the one position, ~~which are to be observed at other plural positions in the observation area, and that of said plural positions whose simulation result shows the arrival direction and the pattern of the intensities of the radiowave most correlated with the observation result at said one position is identified as a location of the radiowave emitting source,~~ the

simulated patterns being obtained while changing the emitting direction of the simulated radiowave, and a position out of the plural positions whose simulated pattern shows the best correlation with the observed pattern at the one position is identified as a location of the radiowave emitting source. Accordingly, a time for preparing data base by the radiowave propagation simulation can be decreased, and the radiowave monitor can be more efficient.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a ~~diagrammatic view~~ schematic diagram showing the radiowave monitoring method according to one embodiment of the present invention.

FIG. 2 is a block diagram of a constitution of the radiowave monitoring apparatus according to the embodiment of the present invention.

FIG. 3 is a ~~diagrammatic view~~ schematic diagram showing a radiowave propagation simulation model.

FIG. 4 is a ~~diagrammatic view~~ schematic diagram showing a coordinate system for computing diffraction coefficients.

FIGs. 5A-5G are views explaining ~~an estimation of a~~ method for estimating the directivity of a transmission antenna of a radiowave emitting source.

FIG. 6 is a flow chart of a process of the radiowave monitoring method according to the embodiment of the present invention.

FIG. 7 is a ~~diagrammatic view of~~ diagram showing a three-dimensional radiowave propagation simulation model.

DETAILED DESCRIPTION OF THE INVENTION

The radiowave monitoring method and apparatus according to one embodiment of the present invention will be explained with reference to FIGs. 1 to 6. FIG. 1 ~~is a diagrammatic view of~~ shows a constitution of the radiowave monitoring method according to the present embodiment. FIG. 2 ~~is a block diagram of~~ shows a constitution of the radiowave monitoring apparatus according to the present embodiment. FIG. 3 ~~is a diagrammatic view of~~ shows a radiowave propagation simulation model. FIG. 4 ~~is a diagrammatic view of~~ shows a coordinate system for computing diffraction coefficients. FIGs. 5A-5G are views explaining ~~an estimation of~~ a method for estimating the directivity of a transmission antenna of a radiowave emitting source. FIG. 6 is a flow chart of the process of the radiowave monitoring method.

(Radiowave Monitoring Apparatus)

The radiowave monitoring apparatus according to the

present embodiment will be summarized with reference to FIG. 1.

A radiowave emitting source 10 is an emitting source for emitting radiowaves to be monitored. Here the radiowave emitting source 10 emits radiowaves of a frequency f_1 . For ~~radiowave monitor of~~ monitoring the radiowaves emitted by the radiowave emitting source 10, monitor stations 12a, 12b, 12c which ~~make~~ conduct holographic observation of the emitted radiowaves are positioned in a monitor area. The ~~sensor monitor~~ stations 12a, 12b, 12c are connected to a center station 16 via circuits 14, ~~which~~. The center station 16 performs radiowave propagation simulation and compares simulation results (simulated pattern) with observation results (observed pattern) to identify ~~a~~ the location of the radiowave emitting source 10.

Each monitor station 12a, 12b, 12c has a radiowave hologram observation and reconstruction apparatus 18 for ~~making~~ performing holographic observation of radiowaves and outputting reconstructed radiowave images. The radiowave hologram observation and reconstruction apparatus 18 includes, e.g., a fixed antenna, and a scanning antenna which scans a scan observation plane. Radiowave images are reconstructed by correlating, for a prescribed observation frequency, ~~received~~ between

signals received by the fixed antenna and ~~received~~ signals received by the scanning antenna with each other to ~~give~~ produce correlated values (two-dimension complex inter-holograms) and reconstructing the two-dimensional inter-holograms.

~~Radiowaves~~ The radiowaves from the radiowave emitting source 10 propagate to the respective monitor stations 12a, 12b, 12c. The radiowaves contain, in addition to ~~a-component~~ components (direct waves) which have propagated from the radiowave emitting source 10 directly to the monitor stations, ~~a-component~~ components (diffracted waves) and ~~a-component~~ components (reflected waves) which have propagated, respectively diffracted and reflected by mountains and other ground objects. In the present embodiment, each monitor station 12a, 12b, 12c ~~makes~~ conducts radiowave hologram observation and reconstructs radiowave images so as to separate the components of respective propagation paths to ~~give~~ obtain their arrival directions and intensities. Radiowaves, which are one kind of waves, can be holographically observed in the same way as in the holographic observation of light; thus, holograms are reconstructed to obtain reconstructed radiowave images, and based on the reconstructed radiowave images, a wave source distribution, intensities, etc. can be investigated. When

component of respective propagation paths can be separated to be observed, the conventional direction finding technique may be used in place of the radiowave hologram observation.

The center station 16 includes simulation means 20 for performing computer simulation of radiowave propagation, a data base 26 for storing ~~a result of a~~ the results of the simulation made in advance by the simulation means 20, and a comparing unit 28 which compares the reconstructed radiowave images observed by the respective monitor stations 12a, 12b, 12c with an electric field intensity distribution ~~given~~ obtained by the simulation. The center station 16 further includes a direction finding trace drawing preparing unit 30 which identifies a location of the radiowave emitting source 10, based on a comparison result ~~given~~ produced by the comparing unit 28 and prepares to output a direction finding trace drawing, and a radiowave activity map preparing unit 32 which prepares and outputs in the form of a radiowave activity map an electric field intensity distribution of the radiowaves from the radiowave emitting source 10 whose location has been identified.

The simulation means 20 includes a map information storing unit 22 which stores information (map information) of a map, geography, ground objects, etc.,

and a radiowave propagation simulator 24 which simulates, with reference to the map information, radiowave emission from the monitor station 12 on the map to simulate radiowave propagation. The radiowave propagation simulator 24 ~~makes~~ performs computer simulation of an electric field intensity distribution that would be generated when the radiowave emission from a monitor station 12 on the map data is simulated, by using, e.g., a ray tracing method (refer to, e.g., IEEE Network Magazine, pp. 27-30, November, 1991) or a moment method (refer to, e.g. R.F. Harrington, Field Computation by Moment Methods, IEEE Press, 1993).

The data base ~~28~~ 26 stores a matrix of the electric field intensity distribution computed by the simulation means 20. The matrix of the electric filed intensity distribution stored by the data base 26 is ~~referred to~~ used by the comparing unit 28 when a location of the radiowave emitting source 10 is identified.

The comparing unit 28 compares a computer simulation result (simulated pattern) of the electric field intensity distribution for the simulated radiowave emission from the monitor station 12a, ~~which have that~~ has been computed by the simulation means 20 and ~~are~~ stored by the data base 26 with a result of actual radiowave holographical observation ~~made~~ (observed

pattern) obtained by the ~~actual~~ monitor station 12a. Based on the result of the comparison, a location of the radiowave emitting source 10 is identified.

The direction finding trace drawing preparing unit 30 traces radiowave propagation paths from the radiowave emitting source 10 whose location has been identified by the comparing unit 28 to the respective monitor stations 12a, 12b, 12c to prepare and output a direction finding trace map 34, and furthermore estimates an antenna directivity of the radiowave emitting source 10, based on the result of the trace.

Based on the location of the radiowave emitting source 10 identified by the comparing unit 28, and ~~an~~ the estimation result of the antenna directivity of the radiowave emitting source 10 ~~given~~ obtained by the direction finding trace drawing preparing unit 30, the radiowave activity map preparing unit 32 commands the simulation means 20 to execute the computer simulation of radiowave propagation to compute an electric field intensity distribution of radiowaves from the radiowave emitting source 10 on the map. ~~A~~ The computed result is displayed and printed out in a radiowave activity map 36 of the radiowave emitting source 10.

The radiowave monitoring apparatus according to the present embodiment, which has the above-described

constitution, is characterized in that, for simulated radiowave emission from the monitor station 12a on the map, an electric field distribution is computed in advance by computer simulation for respective regions corresponding to direction of the radiowave emission. Arrival directions and intensities of radiowaves ~~given~~ obtained by reconstructed images of ~~actual~~ radiowaves actually observed by the monitor station 12a are compared with the electric field intensity distribution ~~given~~ obtained by the computer simulation to thereby identify a location of the radiowave emitting source 10.

(Radiowave Monitoring Method)

Next, the radiowave monitoring method according to the present embodiment will be explained with reference to FIGs. 1 to 6.

Before electromagnetic waves are actually monitored, for simulated radiowave emission from the monitor station 12a on map data, an electric field intensity distribution is computer simulated in a two-dimensional model. The computer simulation for the electric field intensity distribution will be ~~detained~~ detailed with reference to FIGs. 3 and 4. The computer simulation which will be detailed below uses a ray tracing method. The ray tracing method is a method in which it is assumed that a number of rays (light rays) are emitted by a radiowave emitting

source, and the rays are traced along their paths at certain angles. When a ray hits the ground or a building, the ray is further traced in a reflected direction from the position as a reflection point. When a ray hits an edge of a building, a plurality of rays are generated at the point as a diffraction point.

First, the radiowave propagation simulator 24, with reference to map data of an area for the simulation to be executed read from the map information storing unit 22, divides the area for the simulation to be executed into an $M \times N$ matrix of regions. The respective divided regions are represented by 1, 2, ..., $MN-1$, MN in FIG. 3. Information of geography and ground objects is mapped in the map data. In FIG. 3, a building 13a and a building 13b are present in the area.

Subsequently, as shown in FIG. 3, a ray is emitted in an L_k direction from the monitor station 12a, and propagation paths of the ray and electric field intensities of the ray passing through the respective regions are computed. Computed electric field intensities of the ray are recorded as elements of the matrix having ray numbers L_k of emitted rays as the row numbers and region numbers as the column numbers. The matrix for recording the electric field intensities is shown in TABLE 1 below.

TABLE 1

Region Number Ray Number L_k	1	2	3	.	.	.	MN
1	E_{11}	E_{12}	E_{13}	.	.	.	E_{1MN}
2	E_{21}	E_{22}					
3	E_{31}		.				
.	.			.			
.	.				.		
.	.					.	
.	.						.

At this time, the ray has a thickness proportional to a propagation distance from the monitor station 12a as an origin, and when the ray of the thickness covers parts of the respective regions, the ray is considered to have passed the regions. When a plurality of rays have passed through one region, an electric field intensity of that of the rays which ~~gives~~ shows a highest intensity is recorded in the matrix of TABLE 1.

Such simulation process will be explained specifically with reference to a case as shown in FIG. 3 in which a ray emitted from the monitor station 12a as an origin in a direction L_k (emitting direction) is reflected on the building 13a at a point p and arrives at the building 13b at a point q. Here, a line segment interconnecting the monitor station 12a and the point p

is represented by a line segment a, and the line segment interconnecting the point p and the point q is represented by a line segment b.

For regions through which the line segment a of ~~a~~ the ray emitted from the monitor station 12a as an origin to the point p has passed, electric intensities computed by the following Formula 1 are recorded in corresponding elements (L_k , region numbers) of the matrix.

$$E_0 \frac{\exp(-jkr)}{r} \quad (1)$$

~~wherein~~ where E_0 represents an electric field of the radiowaves ~~when~~ emitted by the monitor station 12a, r represents a distance from the monitor station 12a to the centers of the respective regions, and k is a wave number of the radiowaves.

Subsequently, for regions through which the line segment b which has been reflected on the building 13a at the point p and arrived at the point q of the building 13b, electric field intensities computed by the following Formula 2 are recorded in corresponding elements (L_k , region numbers) of the matrix.

$$E_0 \frac{\exp(-jka)}{r} \cdot R \cdot \exp(-jkr') \frac{a}{a+r'} \quad (2)$$

~~wherein~~ where a represents a length of the line segment a, and r' represents a distance from the point p as an origin to the centers of the respective regions.

R represents a reflection coefficient and is given as follows.

First, a complex index of refraction n at the time when a plane wave is incident on a medium 2 from a medium 1 in accordance with Snell's law is expressed by the following Formula 3.

$$n = \sqrt{\frac{\mu_2}{\mu_1}} \sqrt{\frac{\epsilon_2 - j\sigma_2/\omega}{\epsilon_1 - j\sigma_1/\omega}} \quad (3)$$

~~wherein~~ where ϵ_1 , μ_1 and σ_1 respectively represent a dielectric constant, a magnetic permeability and a conductivity of the ~~medium 1~~ medium 1, and ϵ_2 , μ_2 and σ_2 respectively represent a dielectric constant, a magnetic permeability and a conductivity of the medium 2. A reflection coefficient R is expressed by the following Formula 4 using a complex index of diffraction n when an incident electric field is in incidence plane, i.e., in a case of TM (Transverse Magnetic) incidence.

$$R = \frac{\mu_1 n^2 \cos \theta - \mu_2 \sqrt{n^2 - \sin^2 \theta}}{\mu_1 n^2 \cos \theta + \mu_2 \sqrt{n^2 - \sin^2 \theta}} \quad (4)$$

On the other hand, when an incident electric field is vertical to incidence plane, i.e., in a case of TE (Transverse Electric) incidence, a reflection coefficient R is expressed by the following Formula 5.

$$R = \frac{\mu_1 \cos \theta - \mu_2 \sqrt{n^2 - \sin^2 \theta}}{\mu_1 \cos \theta + \mu_2 \sqrt{n^2 - \sin^2 \theta}} \quad (5)$$

Subsequently, line segments c_1, c_2, c_3, \dots of diffracted waves of the ray which has been reflected on the building 13a at the point p and arrived at the point q of the building 13b are given. Here, when the ray is incident on a corner of the building 13b, i.e., the point q is positioned at the corner of the building 13b, a plurality of rays are surface radiated from the corner.

For regions through which the line segments c_1, c_2, c_3, \dots have passed, the following Formula 6 is recorded in corresponding elements (L_k , region numbers) of the matrix.

$$E_0 \frac{\exp(-jk(a+b))}{a+b} \cdot R \cdot D \cdot \exp(-jkr'') \sqrt{\frac{a+b}{r''(r''+a+b)}} \quad (6)$$

~~wherein~~ where b represents a length of the line segment b, r'' represents distances from the point q as an origin to the centers of the respective regions, and D represents a diffraction coefficient, and is computed by the following Formula 7, using the coordinate system shown in FIG. 4.

$$D = -\hat{\beta}'_0 \hat{\beta}_0 D_s - \hat{\phi}' \hat{\phi} D_h \quad (7)$$

~~wherein~~ where $\beta_0, \beta_0', \phi, \phi', \rho^d$ and S^d are physical parameters indicative of the positional relationships shown in FIG. 4. In FIG. 4, E^0 represents an incident wave, and E^d represents a diffracted wave. D^s and D^h are expressed by the following Formula 8 which uses UTD (refer to R.G. Kouyoumjian, P.H. Pthak, Proceedings of

the IEEE, no. 11, pp. 1448-1461, December, 1974) using Fresnel integration function.

$$D_h^s = \frac{-\exp\left(-j\frac{\pi}{4}\right)}{2n\sqrt{2\pi k} \sin \beta_0} \times \left\{ \left[\cot\left(\frac{\pi + (\phi - \phi')}{2n}\right) F(kLa^+(\phi - \phi')) \right. \right. \\ \left. \left. + \cot\left(\frac{\pi + (\phi - \phi')}{2n}\right) F(kLa^-(\phi - \phi')) \right] \right. \\ \left. \mp \left[\cot\left(\frac{\pi + (\phi + \phi')}{2n}\right) F(kLa^+(\phi + \phi')) \right. \right. \\ \left. \left. + \cot\left(\frac{\pi + (\phi + \phi')}{2n}\right) F(kLa^-(\phi + \phi')) \right] \right\} \quad (8)$$

Here, L , $a^+(x)$ and $a^-(x)$ are respectively expressed by the following Formula 9.

$$L = \frac{s^s \rho^d}{s^s + \rho^d}, \quad a^\pm(x) = 2 \cos\left(\frac{2n\pi N^\pm - (x)}{2}\right) \quad (9)$$

N^+ and N^- are expressed by the following Formula 10.

$$N^\pm = \text{int} \left[\frac{\pm \pi + (x)}{2n\pi} + 0.5 \right] \quad (10)$$

The above-described operation is repeated, while changing a direction L_k of the ray emitted by the monitor station 12a (emitting directions) to complete the matrix of an electric field intensity distribution for L_k shown in TABLE 1. The completed matrix of the ~~thus-given~~ electric field intensity distribution is recorded in the data base 26. Thus, the simulation of radiowave propagation (simulated pattern) is completed.

In a case that, as shown in FIG. 1, a plurality of monitor stations 12a, 12b, 12c are positioned, the above-described simulation is performed by the monitor stations 12b and 12c besides the monitor station 12a, whereby the monitor operation can be ~~made~~ performed simultaneously by a plurality of monitor stations. ~~A~~ Since a plurality of monitor stations are used, ~~whereby no insensitive region is present~~ all the regions become equally sensitive, and in addition, increased monitored data can improve accuracy of estimating a location of a radiowave emitting source.

As described above, the radiowave propagation simulation is ~~made in advance~~ conducted before the radiowave ~~monitor~~ monitoring operation is started. The radiowave ~~monitor is made~~ monitoring operation is performed in the sequence of the flow chart shown in FIG. 6.

First, the radiowave hologram observation is performed by the monitor station 12a to obtain reconstructed radiowave images (Step S11). The radiowave hologram observation enables the measurement ~~to be made~~ in with correlation between arrival directions and intensities of radiowaves.

Then, the comparing unit 28 compares arrival directions and intensity patterns (observed patterns) of

the radiowaves based on the reconstructed radiowave images observed by the monitor station 12a with respective patterns (simulated patterns) of column vectors of the matrix of electric field intensity distributions stored in the data base 26 (Step S12).

In radiowave propagation, generally a ~~radiowave~~ radiowave propagation path is reversible between the emission side and the ~~receipt~~ receiving side, and ~~reversibility of~~ a propagation attenuation amount is ~~true~~, also reversible, i.e., a propagation attenuation amount is the same ~~reversibly in~~ when the emission and ~~in~~ the receipt are replaced with one another.

Accordingly, out of column vectors of the matrix of electric field intensity distributions, a region having a region number of a most identical column vector (best correlation) is a location of the radiowave emitting source 10.

The use of the above noted method for ~~thus~~ identifying the radiowave emitting source 10 makes it unnecessary that when it is assumed that a radiowave emitting source is located at one of a plurality of positions in an area to be radiowave-monitored, reconstructed radiowave images observed by a monitor station are computed for the respective points by the computer simulation using map information, which can

improve efficiency of the radiowave monitor.

For the above-described comparison for ~~identity~~ identifying the radiowave emitting source, the usual pattern matching may be used. For example, when a highest level of radiowaves of a reconstructed radiowave image is 0 dB, patterns for radiowave levels above -40 dB are compared to give a correlation coefficient as shapes. As an antenna directivity of a radiowave emitting source 10 is unknown, ~~higher identity in~~ arrival directions of radiowaves ~~may be used~~ can be detected with high accuracy.

When the monitor stations 12b and the monitor stations 12c in addition to the monitor station 12a concurrently perform the ~~monitor~~ monitoring operation, a result of a simulated electric field intensity distribution of radiowave emission simulated in advance is stored in the data base 26 to be compared with a result ~~given~~ obtained by actual radiowave hologram observation.

Next, after ~~a~~ the location of the radiowave emitting source 10 is identified, radiowave propagation paths from the location of the radiowave emitting source 10 identified by the comparing unit 28 to the respective monitor stations 12a, 12b, 12c are traced by the direction finding trace preparing unit 30 to prepare and output a direction finding trace drawing 34 (Step S13).

Path information of rays corresponding to the matrix of the given electric field intensity distribution is recorded in the data base 26 when the computer simulation of an electric field intensity distribution of simulated radiowave emission from the monitor station 12a on the map data is executed, whereby simultaneously with the identification of a location of a radiowave emitting source 10, ~~a~~ the result of tracing radiowave propagation paths can be ~~given~~ obtained without the use of the direction finding trace drawing preparing unit 30.

Furthermore, based on ~~a~~ the result of the above-described trace, antenna directivity of the radiowave emitting source 10 is estimated as follows (Step S14).

First, each monitor station 12a, 12b, 12c ~~perform~~ performs radiowave hologram observation to obtain reconstructed radiowave images. Arrival directions and intensities of the radiowaves for respective propagation paths are extracted from the reconstructed radiowave images obtained by each monitor station 12a, 12b, 12c.

FIGs. 5A to 5C respectively show amplitudes of the radiowaves observed by the monitor stations 12a, 12b, 12c. The thick arrows indicate arrival directions of the radiowaves along propagation paths, and the lengths of the arrows indicate amplitudes of the radiowaves. In the shown example, amplitudes for the respective propagation

paths are denoted by $a_1, a_2, b_1, b_2, c_1, c_2$. On the other hand, radiowave propagation is simulated by ~~a~~ the simulator ~~23~~ 24 on the assumption that a non-directional transmitting antenna is present at the location of the radiowave emitting source 10, which has been already identified, to ~~give~~ obtain amplitudes of the radiowaves for the respective propagation paths by the respective monitor stations 12a, 12b, 12c.

FIGs. 5D to 5F show amplitudes of radiowaves simulated by the respective monitor stations 12a, 12b, 12c. Amplitudes for respective propagation paths are denoted by $a_1', a_2', b_1', b_2', c_1',$ and c_2' . Amplitudes observed for the respective propagation paths $P_1, P_2, P_3, P_4, P_5, P_6$ are divided by amplitudes given by the simulation to ~~give~~ obtain directivity of the transmitting antenna along the respective propagation paths at the location of the radiowave emitting source 10.

In FIG. 5G, the black points indicate directivity along the respective propagation paths. Interpolation computation is ~~made~~ used in consideration of an estimated kind of the antenna to ~~thereby~~ compute directional characteristics for arbitrary directions. The broken line in FIG. 5G indicates the thus-computed directional characteristics.

Based on ~~a~~ the result of the estimation of ~~an~~ the

antenna directivity of the radiowave emitting source 10 by the direction finding trace drawing preparing unit 30, the radiowave activity map preparing unit 32 commands the simulation means 20 to execute the computer simulation of radiowave propagation to compute an electric field intensity distribution of the radiowaves from the radiowave emitting source 10 on a map. ~~A~~ The result of the computation is displayed and printed out as a radiowave activity map 36 of the radiowave emitting source 10 (Step S15).

Thus, the radiowave emitting source 10 in a certain area is identified, and at the same time, a direction finding trace drawing is prepared, a directivity of the transmitting antenna of the radiowave emitting source 10 is estimated, and a radiowave activity map is prepared, and the radiowave ~~monitor~~ monitoring operation is completed.

As described above, according to the present embodiment, when it is assumed that a radiowave emitting source is present at one of a plurality of positions in an area, it is not necessary to compute by the computer simulation reconstructed radiowave images observed by the monitor station, which can decrease the time for preparing the data base and accordingly can improve radiowave monitoring efficiency.

Next, the radiowave monitoring method and apparatus according to another embodiment of the present invention will be explained with reference to FIG. 7. FIG. 7 ~~is a diagrammatic view of~~ shows a three-dimensional radiowave propagation simulation model in the present invention.

The radiowave monitoring method and apparatus according to the present embodiment is characterized in that an electric field intensity distribution of simulated radiowave emission by a monitor station 12a on map data is simulated by using a three-dimensional model, thereby creating simulated patterns. The present embodiment is the same as the above-described embodiment except that an electric field intensity distribution is simulated by using a three-dimensional model.

First, as shown in FIG. 7, a monitor area is divided in $x \times y \times z$ unit spaces, and the respective spaces are represented by space numbers 1, 2, 3, ..., $xyz-1$, xyz .

Subsequently, one ray is emitted in an L_k direction (emitting direction) from a monitor station 12a on map data. Propagation paths of the ray and electric field intensities of the ray at the time when the ray passes the respective unit spaces are computed in the same way as in the two-dimensional model of the above-described embodiment. ~~Computed~~ The computed electric field intensities are recorded as elements of the matrix of

emitted ray numbers L_k in the rows and unit space numbers in the columns.

At this time, the ray has a thickness proportional to a propagation distance from the monitor station 12a as an origin, and when the ray of the thickness covers parts of the respective regions, the ray is considered to have passed the regions. When a plurality of rays have passed through one region, an electric field intensity of that of the rays which ~~gives~~ shows a highest intensity is recorded in the matrix.

When a ray emitted from the monitor station 12a in an L_k direction is reflected on a building 13a at a point p or diffracted at a point q of building 13b, electric field intensities of the ray are computed in the same way as in the above-described embodiment. Directions of the reflection and the diffraction are determined in consideration of three-dimensional information of the buildings 13a, 13b.

The above-described operation is ~~repeated~~, repeated while three-dimensionally changing the directions of the rays emitted by the monitor station 12a (emitting directions) to ~~thereby~~ complete the matrix of an electric field intensity distribution of the rays L_k in the same way as in the two-dimensional model. The thus-obtained matrix (simulated patterns) of an electric field

intensity distribution is recorded in the data base 26. Thus, the radiowave propagation simulation is completed.

Using a result of the above-described radiowave propagation simulation, the radiowave ~~monitor~~ monitoring operation can be performed in accordance with the flow chart shown in FIG. 6 in the same ~~was~~ manner as in the above-described embodiment.

As described above, according to the present embodiment, it is unnecessary that when it is assumed that a radiowave emitting source is located at one of a plurality of positions in an area to be radiowave-monitored, reconstructed radiowave images observed by a monitor station are computed for the respective points by the computer simulation using map information, which can decrease ~~time of~~ the time for preparing data base and can improve efficiency of the radiowave monitor.